CHAPTER 15

The Domestication of the Pig *(Sus scrofa)*

New Challenges and Approaches

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Introduction

Pigs are the victims of their own success in two ways. First, wild forms are distributed over most of the Old World except for the very dry and the very cold regions. This contrasts with other animals like sheep, whose much more limited distribution constrains the search for domestication to a restricted area. It also means that archaeological finds outside that area must come from domestic animals. The wide distribution of pigs and their close relatives (Groves 1981; Oliver 1993) means that a simple geographical diagnosis of domestication is usually impossible.

Second, pigs are adaptable and generalized omnivores. They may, therefore, have a wider range of possible relationships with humans than do other species. At one end of the spectrum is unambiguous hunting, and at the other is close domestic control. But in between is a "gray area," which is perhaps wider and more complex than for most other species. Both urban and rural domestic pigs may at times wander freely and forage for themselves, returning to their owners each evening. In the medieval period, pigs were driven into woodlands to forage for acorns, a practice known as *pannage*. Such free-ranging behavior is not what we associate with conventional domestic animals. There can be greater complexities. Among the Etoro of New Guinea, domestic female pigs roam freely round the villages and stray into the surrounding forests, where they meet and interbreed with feral males. All breeding takes place this way since males in domestic litters are all castrated (Rosman and Rubel 1989). In fact, the unique biology and behavior of pigs present special challenges to the study of their domestication that have caused some to question whether the threshold we term "domestication" is really relevant to pigs. This chapter explores some of these challenges for the study of pig domestication and the growing range of new approaches that can be used to address them.

Prior Research

The earliest studied assemblages of animal bones included those from pigs. These came from various European sites such as Danish shell middens, Swiss lake dwellings, Italian *terramare* settlements, and others. By the end of the nineteenth century, it was clear that two main forms were represented: the wild boar and the domestic porker. The Danish zoologist Herluf Winge used both metrical and morphological criteria to separate them, establishing ground rules that are often still used today; for example, lower M3s greater than 40 mm in length are likely to come from wild boars, and those under 40 mm in length are likely to come from domestic individuals, although there is an overlap (Winge 1900).

Winge (1900) believed that prehistoric European domestic pigs (which, following earlier writers, he termed *Sus scrofa domesticus* or *S. s. palustris*) were descendants of the wild boar of Europe, northern Asia, and North Africa (*Sus scrofa ferus*). Modern domestic pigs in Southeast Asia were more similar to the local wild boars, which he believed might be a different species (*Sus vittatus*). Beyond this, however, he did not seek the geographical origins of domestication. Soon various ideas were put forward. Pira (1909: 373), working on Swedish material, argued for local domestication because the earliest domestic pigs were the closest to wild boars in both size and morphology. However, archaeology was finding ever-earlier agriculture in the Near East, with pigs as part of the package (Flannery 1983). As a result, the dominant view of the mid-twentieth century was that pigs were domesticated in the Near East and brought to Europe by immigrant farmers (e.g., Childe 1958: 34). A few dissenters, like the geographer C. O. Sauer (1952), preferred a Southeast Asian origin for domestic pigs. But nearly all researchers argued for a limited geographical origin for pig domestication.

The hypothesis that domestic pigs spread from a limited geographic area of initial domestication was challenged initially by Eric Higgs and colleagues in the later 1960s. They argued that domestication as a threshold event was an illusion, and that there was a multiplicity of potential, intermediate states for all animals and plants (Higgs and Jarman 1969). With regard to pigs, Winge's metrical division was challenged, and the case was made for intermediate or semidomestic pigs under extensive control; a trend toward closer relations could occur anywhere, not just in the previously recognized centers (e.g., Jarman 1976a; Zvelebil 1995). The situation can now best be described as being in a state of flux. It is becoming increasingly unclear whether we should be looking for domestication as a threshold event, how we would recognize it in the archaeological record, or even whether we can effectively define domestication in a broadly applicable way.

Defining Domestication

Over the years, a number of books and articles have attempted to devise a satisfactory, general definition of a domestic

animal. Many authors have focused exclusively on cultural factors, while others have focused only on biological ones, with insufficient attention paid to integrating the two. In his seminal review of the role of animal behavior in domestication, Price (1984: 3) rightly states that "it is difficult to formulate a definition of domestication that is general enough to account for the wide variation observed in different species, in different captive environments, yet specific enough to be meaningful in terms of the biological processes involved." Nevertheless, he attempts to define domestication as "that process by which a population of animals becomes adapted to man and to the captive environment by some combintion of genetic changes occurring over generations, and environmentally induced developmental events reoccurring during each generation."

This is a broad definition, which essentially emphasizes captivity (i.e., direct human control) as a basic requirement. Some have argued, however, that the very terms "domestic" and "wild" are, in fact, the extreme ends of a continuum, along which a whole host of environmental, biological, and cultural factors vary, and various combinations of these factors may have either gradually or rapidly altered the behavior and genetics of the animals (Ervynck et al. 2002: 50). As a result of this somewhat more complex view of human-animal relationships, a number of intermediate stages of domestication have been proposed, such as cultural control (Hecker 1982: 219; Hongo and Meadow 1998, 2000), predomestic (Vigne and Buitenhuis 1999), and intermediary stage (Ervynck et al. 2002). These imply that the terms "domestic" and "wild" merely describe the extremes of a spectrum defined as follows (after Ervynck et al. 2002: 50): "wild" populations not experiencing (in the most simplified case) any direct or indirect influence of human behavior; "domestic" populations being characterized by survival, reproduction, and nutrition under complete human control.

In this definition, an animal can only be considered to be domestic where there is a conscious and prolonged intervention by humans to control many or all aspects of its life cycle. Although this definition is one with which we would agree, it means that true domestication is still the end point of an ongoing process, where, in its early/intermediate stages, morphological, genetic, and demographic shifts can still occur.

Although a continuum of relationships may occur in all species, in pigs the actual domestic or wild status of individuals or populations can be particularly difficult (if not impossible) to identify. In most of the world, domestic pigs live in areas also populated by wild boars, and inevitably interbreeding occurs regularly. In addition, domestic pigs are often kept in free-range conditions and can escape, creating entirely feral populations. This means that pig populations cannot be classified so easily as wild or domestic, and other possible conditions must be considered. Mayer and Brisbin (1991) and Mayer et al. (1998) consider four different types of pig populations: wild, domestic, feral, and genetic hybrids, although intermediates between even these may occur.

If this is the situation in the modern world, it is likely that a similarly wide range of relations between humans and pigs must have occurred in the past. This especially could be so for the early stages of the domestication process, when control of animal populations might have been relatively loose, and genotypic and phenotypic changes in domestic animals were still minimal. The likely contiguity of wild and domestic pig populations has lead Hongo and Meadow (1998: 89) to propose that criteria for the identification of the origin of domestication in bovids may not be entirely applicable to suids. Thus, rigid definitions of what represents a wild or domestic pig are fraught with problems, which, in the end, largely boil down to personal preference or arguments over semantics.

Detecting Domestication in Pigs

It is clear from the discussion in the previous section that domestication is difficult to define for any species, and probably particularly so for the pig. It would, therefore, be naive to expect straight or easy answers from the archaeological record. At various points along the cline from wild to domestic, animals may change their biology, behavior, and attitude toward humans in many different ways and to varying degrees. It follows that changes in exploitation strategy resulting in a shift along the continuum cannot be analyzed in a univocal way, and that a diversity of approaches is required. In addition to the complexity of the domestication process per se, we also have to consider climatic, environmental, geographic, chronological, and cultural variables that provide the context for domestication.

The three authors of this chapter make up the Durham Pig Project, which is examining pig domestication and early husbandry around the world. Because of the complexities we have outlined above, we decided that we could not confine our analysis to a specific area (e.g., the Near East or China, likely to contain the earliest stages of domestication), a specific period (e.g., the Mesolithic/Neolithic transition), or a single methodological approach. Work carried out in the last few years by other authors and by ourselves suggests that medieval pigs can be as informative about the domestication process as their Neolithic counterparts, and that the onset of domestication in peripheral areas may also be illuminating about the earliest origin of the phenomenon.

In the following sections, we therefore present some results of multiple approaches and techniques used by others and by ourselves to document pig domestication. We emphasize that although each approach and technique has its own unique potential, we feel strongly that a combination of some or all of these is essential for a fuller understanding of the domestication process.

Zoogeographic Markers

One of the primary criteria used by zooarchaeologists to infer the presence of domestic animals is the appearance

of a species outside its natural range, or in locations where it is unlikely to have reached without the intervention of humans (e.g., on remote islands). Davis (1987: 133) goes so far as to state, "The sudden arrival of a new species is often a sure sign that it was introduced as domestic stock by humans." The appearance of sheep in archaeological sites in southern France, Corsica, and South Africa, sheep and goats in Greece and Britain, horses in the Levant, cats in Cyprus, dogs in South America, and turkeys in Mesoamerica are all given as examples of and evidence for the introduction of domesticates.

For pigs, however, the high degree of morphological similarity between the various species of *Sus* means that in certain parts of the world it is difficult for us to ascertain which species of *Sus* we are dealing with in the archaeological record. In island Southeast Asia, for example, several different *Sus* species (*Sus scrofa*, *Sus celebensis*,[1] *Sus cebifrons*, and *Sus barbatus*) are found, yet apparently maintain significant differences in morphology, ecology, and behavior (Rothchild and Ruvinsky 1998). All these pig species were certainly exploited by Holocene peoples, and some like *Sus scrofa* (and possibly even *Sus celebensis*) were even transported by them outside their natural habitat. Unfortunately, continuing confusion over the present-day taxonomy of these island suids, and problems with the specific identification of their fossil remains, leave us very little idea which species are present in the archaeological record, let alone their wild, feral, or domestic status.

To make matters worse, interspecies hybridization between introduced *S. scrofa* and the other indigenous species cited above has been claimed (Lotsy 1922; Blouch and Groves 1990), and this could have occurred in the past. For example, Groves (1981) claims that the feral and domestic pigs in New Guinea at the time of European contact were in fact hybrids of *Sus scrofa* and *Sus celebensis*.[2] If correct, there could be little doubt that these animals were initially fully domesticated when introduced. However, this important hypothesis has yet to be conclusively proven, and is one where genetic analysis could be employed on both modern and ancient material to prove or disprove this theory.

Even where introduction by people is the most likely explanation for the presence of pigs, can we be sure that the animals were actually domestic? In the case of New Guinea, although there is still much debate as to precisely when pigs arrived,[3] their appearance is commonly thought to be a direct consequence of introduction as a domesticate by humans. However, Bulmer (conversation with Dobney, 12 September 2002) contends that the transport of pigs to New Guinea does not necessarily imply domestication, and that wild (or feral) pigs might just as easily have arrived on New Guinea without human assistance.

The spread of Neolithic farmers into certain parts of northwestern Europe appears to have also heralded the arrival of fully domesticated relatives of the indigenous wild boar (see below). With their genetic origins outside the area of introduction, these discrete populations should be recognizable both in terms of their morphology and their genetics. On the Baltic island of Gotland, pig bones are one of the most common mammal species' remains excavated from Middle Neolithic settlements (e.g., Österholm 1989; Lindqvist and Possnert 1997). Mandibles were also important as grave offerings. There was no land bridge between Gotland and the mainland when wild boars were recolonizing Scandinavia after the last glaciation. Although wild boars have been known to swim significant distances between islands, Gotland is some 80 km from mainland Sweden, so it is highly unlikely that wild boars could have colonized the island by themselves during the Early Holocene. All the ^{14}C-dated examples from "Mesolithic" contexts in Stora Förvar Cave have turned out to be Neolithic intrusions (Lindqvist and Possnert 1997), so the high frequency of pig bones found in Middle Neolithic sites on Gotland clearly indicates that humans introduced pigs sometime during the Neolithic. But does this imply that these pigs were domesticated? There has been much debate about this. Ekman (1974) argued that they were morphometrically wild. Jonsson (1986) believed they were domestic because they must have been under close control when actually shipped across to Gotland. Österholm (1989) pointed out that some funerary rituals required the mandibles of 20 or 30 pigs, and such numbers could not be hunted to order when needed, so the animals must have been domestic. However, Rowley-Conwy and Storå (1997) aged the mandibles and showed that they came from pigs killed at various times during the year, suggesting that the jaws were trophied before deposition in the graves, and thus need not have been domestic. Biometry has been used to argue that the pigs from Gotland were domestic (Benecke 1994), and it has also been used to make the case for their having been wild (Rowley-Conwy and Storå 1997). We are currently conducting our own biometrical analysis of this material, which suggests that these animals are intermediate in size between wild and domestic mainland pigs, and so the debate continues.

The limited range of wild mammals from Ireland suggests that most (including pigs) have been introduced by humans at varying times in the past (McCormick 1999). The presence of Mesolithic pigs suggests that this introduction occurred prior to the beginnings of agriculture, and that pigs were deliberately transported to Ireland by humans and released to found a hunted population. Their pre-Neolithic date means that we can be reasonably confident that they were indeed wild boars and not domesticated animals. A similar scenario has been suggested by Vigne and Buitenhuis (1999) for the introduction of pigs to Cyprus in the Early Pre-Pottery Neolithic period, commonly thought to predate pig domestication in the Near East. In this case, Vigne et al. suggest that the animals were already on the way toward domestication. They suggest that a loose relationship must have existed between transporter (human) and transported (pig), which signifies some kind of predomestication phase. This term

involves "a form of husbandry without any apparent morphological change in the animals" (Vigne and Buitenhuis 1999: 55). In the case of pigs, therefore, the mere presence of remains does not provide definite proof of their domestic status. This requires the application of other, newer techniques such as those outlined below. In the meantime, we must remember there are a number of instances when humans have transported clearly wild animals to islands to found populations for hunting—the earliest case currently being the introduction of a marsupial, the cuscus (*Phalanger orientalis*), to New Britain at 19,000 BP (Flannery and White 1991).

Biometry

Despite the difficulties of defining what exactly a domestic population is, and the inadequacy of using size alone to address this question, biometry, however, remains the most widespread tool used by zooarchaeologists in considering domestication. There are reasons to believe that such a reliance on biometrical analysis has solid foundations, although some simplistic interpretations of metric data carried out in the past may need revision.

The main challenge to the metrical method came from the growing awareness of the potential range of animal-human relationships revealed by history and anthropology. As mentioned above, Higgs and his Cambridge-based research group in particular asked whether there ever was "a 'beginning' of either agriculture or domestication" (Higgs and Jarman 1969: 31), and this led them to seek out problem cases. Working on the Neolithic pigs from Molino Casarotto in northern Italy, Jarman (1976a: 528) concluded that the animals "bridge the accepted size ranges of wild pigs and Neolithic domestic pigs from sites such as Seeberg Burgäschisee-Süd. Furthermore, there is no indication that we are dealing with two separate populations of pigs as regards size, as no strongly bi-modal tendency is apparent in the size distribution of the bones." From this, Jarman concluded that no simple classification into wild or domestic was adequate to describe these pigs: Molino Casarotto contained a single pig population, intermediate between wild and fully domestic.

Jarman's work, however, was just as problematic as the simplistic view that it sought to replace (Rowley-Conwy 2003). First, he assumed that because he could not demonstrate whether the Molino Casarotto pigs were metrically wild or domestic, it followed that they were, therefore, behaviorally in between the two. This is not a valid extrapolation. Second, his metrical argument for the intermediate status of the pigs from Molino Casarotto derived from a comparison with Seeberg Burgäschisee-Süd. The two sites, however, are on different sides of the Alps and in totally different environmental zones. More recent work has shown that there is considerable environmentally linked size variation both in prehistoric pigs (Davis 1981; Rowley-Conwy 1995) and in recent wild boars in various regions, so Jarman's initial metrical conclusion may be flawed (Rowley-Conwy 2003).

One of the most significant recent advances in *Sus* biometrical methods is the work of Payne and Bull (1988). These authors revised the analysis of biometrical data from a number of important prehistoric sites from Europe and western Asia by adopting a size index scaling technique (see Meadow 1999). By taking into account to what extent measurements were smaller or larger than a particular standard—in this case, the mean taken from a sample of modern wild boar skeletons from Turkey—the authors could plot measurements of different bones on the same graph. Although this system was not new in zooarchaeology (e.g., see Ducos 1968; Uerpmann 1979; Meadow 1981), it was extensively applied to pig assemblages for the first time. This system has the advantage of increasing sample size by lumping measurements of different bones together. In addition, when different measurements are plotted separately but on the same scale, it is possible to detect variations in the relative dimensions of different body parts between pig populations.

The importance of the introduction of this method can hardly be overestimated, as biological change (resulting from domestication or subsequent selection) cannot be reduced to mere size diminution. Size variation often goes hand in hand with morphological change. For instance, typical characters that are used to separate domestic from wild pigs include the shortening of the snout—particularly notable on the relative dimensions of the lachrymal bone (Jonsson 1986: 125; Clutton-Brock 1987: 72). In addition, a reduction in relative brain size following domestication has been well documented in a range of species (Herre and Röhrs 1973; Kruska 1988). In fact, some of the biggest changes in the overall size of the brain, as well as in a variety of its selected functional systems, have been noted in pigs (Kruska 1988: Tables 13.1 and 13.2). Although rarely applicable to archaeological material (because complete skulls are very uncommon), this approach can be useful when using modern skeletons to make extrapolations about the past. For instance, Groves (1989) has hypothesized that the "wild" pigs from Sardinia and Corsica, because of their relatively large brain capacity, derive from wild, rather than domestic, animals introduced to the islands in prehistoric times. Consequently, these pigs should be regarded as genuinely wild rather than feral, in contrast to the feral status suggested for the mouflon (*Ovis musimon*) on the same islands.

To show the way these biometrical approaches have developed over time and are improving our understanding of pig domestication, we now present a number of examples taken from our ongoing pig domestication research. Figure 15.1 presents a first set of case studies, in which modern data are used as an aid for our interpretation of the archaeological material; it directly compares the greatest length of the astragalus of pigs from a modern wild population with results from several archaeological populations across Europe. The modern wild Turkish population (from Payne and Bull 1988) includes both females and males, juveniles and adults, and groups quite tightly, with a coefficient of variation of 5.7 (Figure 15.1a). Sværdborg I is an Early Mesolithic site where only wild boars would be expected; the large sample has a normal distribution and a coefficient of variation (cov) of 4.7,

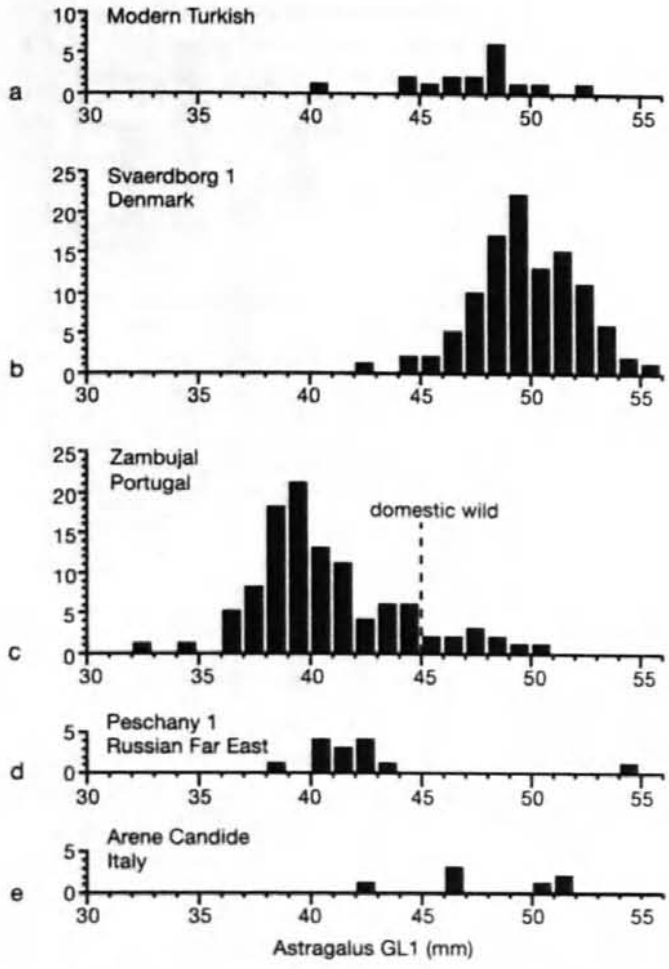

FIGURE 15.1 Astragalus length (GLl) for a variety of samples: (a) Modern Turkish (n = 18, cov = 5.7) (Payne and Bull 1988); (b) Sværdborg, Denmark, early Mesolithic (n = 115, cov = 4.7) (Rowley-Conwy unpublished data); (c) Zambujal, Portugal, Copper Age (n = 105, cov = 8.1) (von den Driesch and Boessneck 1976); (d) Peschany 1, Russian Far East, Iron Age (n = 14, cov = 8.8) (Rowley-Conwy 1999); (e) Arene Candide, Italy, Early Neolithic (n = 7, cov = 5.3) (Rowley-Conwy unpublished data).

supporting the interpretation that a single population is present (Figure 15.1b). The Portuguese Copper Age assemblage from Zambujal, however, is very different (Figure 15.1c). Here the distribution of normalized postcranial elements is strongly negatively skewed, which is generally interpreted as a mixture comprised primarily of many domestic animals that form a "peak" in the distribution, and a "tail" consisting of larger-bodied wild specimens extending to the right of the graph (von den Driesch and Boessneck 1976). The skewness cannot be the result of a concentration on one sex (e.g., smaller females) because, if this were the case, the coefficient of variation would resemble that of the Turkish control population or be even smaller. The Zambujal coefficient of variation, however, is 8.1, larger than that of the previous samples considered. This supports the interpretation that more than one population is indeed present. The larger animals, interpreted as wild, match the size of local Mesolithic wild boars, while the smaller ones, interpreted as domestic, are similar in size to late prehistoric domestic pigs from elsewhere in Iberia (Rowley-Conwy 1995), further supporting the interpretation of von den Driesch and Boessneck (1976). "Peak and tail" distributions are quite common in Neolithic and Bronze Age Europe (Rowley-Conwy 2003). A similar pattern is seen in the small sample of postcranial bones from Peschany 1, an Iron Age site near Vladivostok in the Russian Far East (Rowley-Conwy 1999; Figure 15.1d), although the wide separation between the specimens that comprise the peak and tail in this case indicates that in these areas at least, the wild and domestic populations did not interbreed very much. This, in turn, implies that these domestic populations were under close control and were not kept under an extensive regime of the kind proposed by Jarman (1976a).

Not all areas of Europe show such clear-cut patterns, however. The difficulties in interpreting the intermediate size of the pigs from the island of Gotland were mentioned above. Another puzzling dataset comes from the Early Neolithic of Arene Candide in Italy (Figure 15.1e). The sample is very small but does not suggest the presence of more than one population. In such cases, the problem is more difficult. Metrically, the population could be wild, domestic, or in some extensive "in-between" state. It has been argued that these animals were wild (Rowley-Conwy 1997, 2000), but the possibility remains that they were domestic (Sorrentino 1999). Prehistoric North Italian pigs have attracted a fair amount of debate in the last 30 years and have become one of the key topics for our understanding of the phenomenon of pig domestication. Therefore, it is worth discussing the problem in greater depth, on the basis of further work we have carried out in the last few years.

To understand the intriguing evidence from Arene Candide, it is necessary to compare it with larger datasets from other sites. An opportunity is provided by the reanalysis of the Middle Neolithic animal bones from Rivoli, which, like the above-mentioned site of Molino Casarotto, was originally studied by Jarman (1976b). This restudy was carried out by Piper, supervised by one of us (UA) (Piper 2001; Albarella et al. in preparation b). Rivoli is near Lake Garda, east of Arene Candide; both are south of the main Alpine watershed (see Figure 15.2 for the location of sites in the Alpine region).

Figure 15.3a compares lower third molar measurements of pigs from Arene Candide and Rivoli. In addition, we have included the data from the Swiss Late Neolithic site of Seeberg Burgäschisee-Süd, as these were the data used by Jarman in his assessment of the case for swine domestication at Molino Casarotto. The material from Seeberg Burgäschisee-Süd has also been reanalyzed as part of our current project on pig domestication and early husbandry (Albarella et al. in preparation b). The Seeberg Burgäschisee-Süd teeth are much larger than those from Rivoli and Arene Candide, while those from the latter two sites seem to be of comparable size. However, the only measurable lower third molar from Early Neolithic Arene Candide plots in the lower part of the Seeberg Burgäschisee-Süd distribution. A simplistic analysis of this distribution could lead to the suggestion that the pigs from Seeberg Burgäschisee-Süd (and perhaps the Early Neolithic M3 from Arene Candide) are wild, and those from the Middle Neolithic of Arene Candide and Rivoli are domestic.

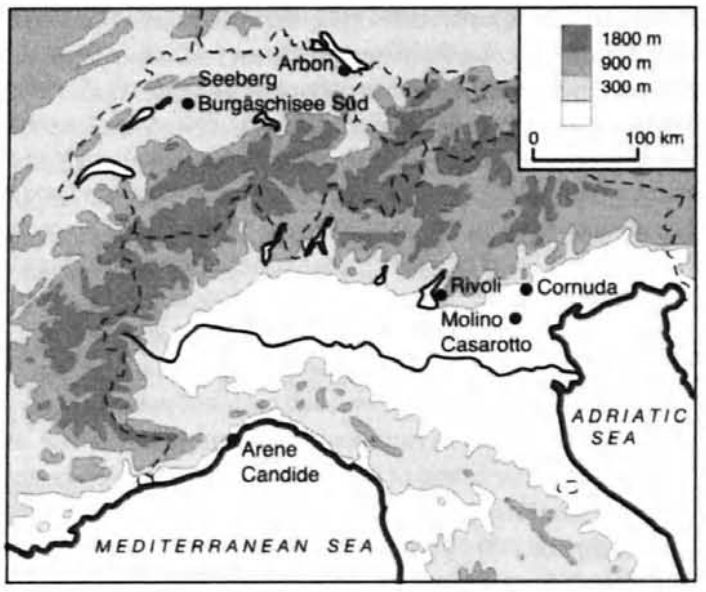

FIGURE 15.2 Map of the Alpine region and northern Italy showing the locations of sites mentioned in the text.

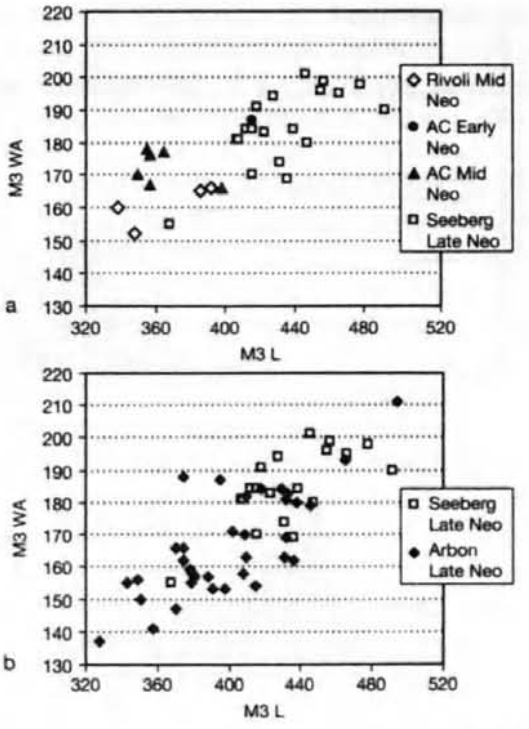

FIGURE 15.3 M3 measurements from Alpine Neolithic sites: (a) Rivoli Mid-Neolithic, Arene Candide Early and Mid-Neolithic (AC), and Seeberg Burgäschisee-Süd Late Neolithic (Seeberg); (b) Seeberg Burgäschisee-Süd (Seeberg), Arbon.

In fact, in the original publication, the pigs from Seeberg Burgäschisee-Süd were interpreted as being predominantly wild (Boessneck et al. 1963). This conclusion was questioned by Payne and Bull (1988: 35), who suggested that there were perhaps more domestic pigs represented at the site than originally suggested. Our own analysis (see below) further supports this latter view.

Figure 15.3b compares the measurements from Seeberg Burgäschisee-Süd with those from Arbon, another Late Neolithic Swiss site to the east that is slightly later than Seeberg Burgäschisee-Süd (Figure 15.2). Although the Seeberg Burgäschisee-Süd teeth are on average quite a lot larger than the Arbon ones, overlap occurs. If we interpret all the Seeberg Burgäschisee-Süd M3s as deriving from wild specimens, it would follow that all specimens in the top part of the Arbon distribution are also wild, with no clear separation from the domestic population. This is, however, extremely unlikely, as extensive work on the Arbon data (Sabine Deschler, Elisabeth Marti Graedel, and Jörg Schibler personal communication May 2001; Albarella et al. in preparation a) has proven that measurements of pig postcranial bones from this site have the peak and tail distribution typical of the European Neolithic, with a large predominance of domestic animals. An alternative explanation for Figure 15.3b is, then, that the domestic-wild divide, in fact, is placed higher up in the distribution, and that only the six largest specimens from Seeberg Burgäschisee-Süd and the two largest from Arbon are wild, with most of the rest being domestic. This means that the domestic pigs from Seeberg Burgäschisee-Süd are not only mostly larger than the Arbon ones, but also larger than those from Arene Candide and Rivoli. Whether this is because of different environmental conditions or the interbreeding of the Seeberg Burgäschisee-Süd domestic pigs with wild ones, it is clear that the populations from north and south of the Alps are different and that any comparison between the two areas must be interpreted cautiously. It is likely that conditions north of the Alps were colder, and this may have affected animal size. In particular during the period of occupation of Seeberg Burgäschisee-Süd, there seems to have been a worsening of the climatic conditions, which seems to be associated with an intensification of hunting (Schibler et al. 1997).

One further element that must be taken into account is the degree to which these differences between sites can be the result of a different sexual composition of the pig assemblages under investigation. At Arbon, on the basis of the morphology of the canines and their alveoli, there seems to be a predominance of males—a ratio of 22:12. At Seeberg Burgäschisee-Süd, the sample is unfortunately too small to draw any firm conclusion. Only three mandibles could be sexed, and these were all from females. It must be clarified that here we are counting only mandibles and not isolated teeth, as these latter are much prone to a recovery bias between sexes. This evidence suggests that the average larger size of the Seeberg Burgäschisee-Süd pigs is unlikely to be the result of a sex bias since the Arbon population includes individuals of both and sexes and, if anything, the larger males are more numerous. At Rivoli, as at Seeberg Burgäschisee-Süd, the sample of sexed mandibles is too small to be significant, although isolated canines indicate a predominance of females. Although this is interesting because a recovery bias should favor the larger male tusks, these latter are sometimes used as tools, which might explain their rarity in the assemblage (i.e., they may have been disposed of outside the excavated area).

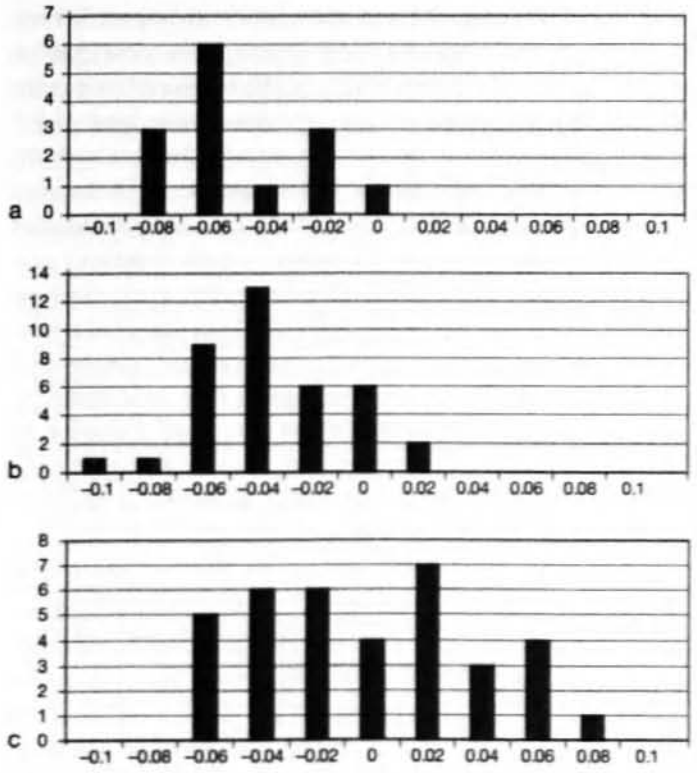

FIGURE 15.4 Variation in *Sus* tooth and bone measurements at the Mid-Neolithic site of Rivoli (northern Italy). Log ratio compared to a standard ("0") modern wild population from Turkey (Payne and Bull 1988). (a) Tooth lengths (n = 14); (b) tooth widths (n = 38); (c) postcranial bones (n = 36).

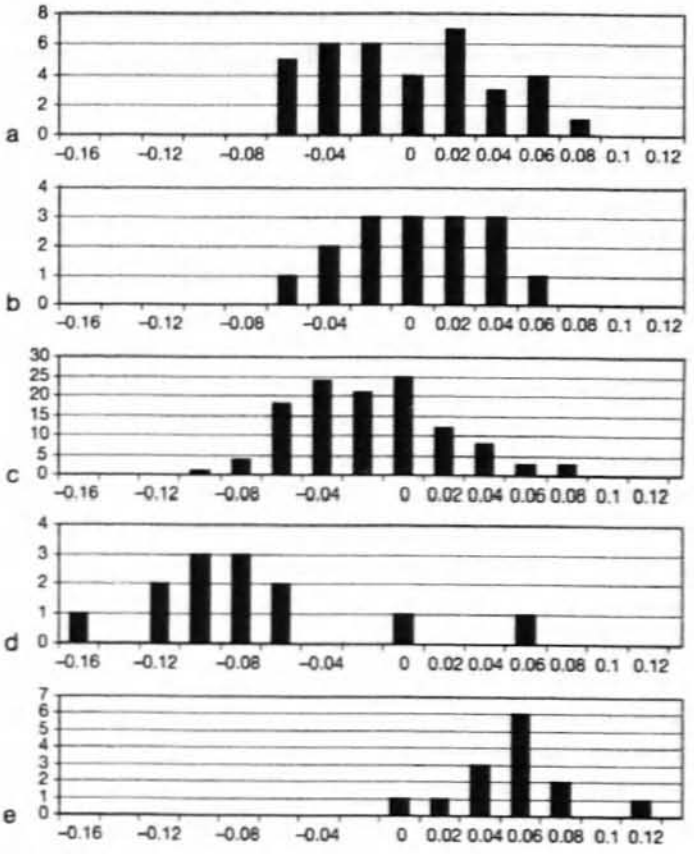

FIGURE 15.5 Variation in *Sus* postcranial bone measurements at three Neolithic sites in northern Italy. Log ratio compared to a standard ("0") modern wild population from Turkey (Payne and Bull 1988). (a) Rivoli, Mid-Neolithic (n = 36); (b) Arene Candide, Early Neolithic (n = 16); (c) Arene Candide, Mid-Neolithic (n =119); (d) Arene Candide, Late Neolithic (n = 13); (e) Cornuda, Late Neolithic (n = 14).

It is important to remember, however, that in pigs, teeth are much less sexually dimorphic than are postcranial bones (see Payne and Bull 1988). This means that variation in tooth size is unlikely to be linked to the sex of the animal, while sex may play a larger role in variation in the size of postcranial elements. More work is clearly needed to determine the differential degree to which sex affects the size of postcranial bones and teeth in pigs and how these differences influence the metric patterning we see in the archaeological record.

Returning to the Italian material and a closer look at the Rivoli data, since the sample size of M3s from the site is so small we have used a size index scaling technique to compare measurements of tooth lengths, tooth widths, and postcranial bones (Figure 15.4). This diagram clearly demonstrates that the size of the Rivoli pigs cannot be characterized easily. Tooth measurements from the Rivoli pigs tend to be somewhat smaller than the Turkish modern wild boar standard, while the postcranial elements of these ancient pigs are relatively larger. Consequently, relying exclusively on the small tooth size of the Rivoli pigs as an index of body size would be a mistake. Since it is highly unlikely that the Rivoli assemblage is represented by teeth of domesticates and postcranial bones of wild animals, we have to consider the possibility that the size of the teeth and the postcrania in pigs do not co-vary. Figure 15.5 compares normalized postcranial data from Rivoli with those from various levels at Arene Candide. As with the teeth (Figure 15.3), the postcranial measurements from Middle Neolithic Arene Candide are comparable to those from Middle Neolithic Rivoli (Figure 15.5a, c). This suggests that Arene Candide pigs also had relatively larger bones than teeth. However, there is a dramatic reduction in body size in the pigs from Late Neolithic levels at Arene Candide (Figure 15.5d) (see also Rowley-Conwy 1997). The Late Neolithic pigs can confidently be interpreted as domestic with two probably wild, large outliers. The separation into two distinct wild and domestic populations—a classic peak and tail pattern—that seems to have occurred by the Late Neolithic is not reflected in the earlier levels at Arene Candide or at Rivoli. On the basis of these metric data and other evidence, it was previously suggested (Rowley-Conwy 1997) that pigs may not have been domestic until the Late Neolithic at Arene Candide. This subsequent and more extensive analysis, however, makes it clear that that the situation is more complex.

All of these pigs are smaller than the extremely large pigs from the Italian Late Neolithic site of Cornuda. Since residents of Cornuda seem to have relied primarily on hunted game, especially deer (Riedel 1988), there is some reason to believe that these large pigs are mostly, if not exclusively, wild. If so, how do we classify the pigs from Early and Mid-Neolithic levels at Arene Candide and Rivoli that are intermediate in size between the presumed wild pigs from Cornuda and the

presumed domestic pigs in Late Neolithic levels at Arene Candide? There are three possible hypotheses that can be offered to explain these patterns.

The first is that the Early and Middle Neolithic pigs from Arene Candide and Rivoli are wild. However, this hypothesis is unlikely because it would be difficult to explain their smaller absolute body size compared to that of the presumed wild pigs from Cornuda, as well as the relatively small size of their teeth. Also, this would imply that northern Italian wild pigs had smaller teeth than did domestic pigs from Switzerland, which is unlikely, even if we take into account possible climatic and environmental differences.

Alternatively, one might argue that the Early and Middle Neolithic pigs from Arene Candide and Rivoli are fully domestic. While this would seem a more likely explanation for these osteometric data, it would still cause major interpretative problems. If this were the case, the dramatic size diminution occurring in the Late Neolithic would be hard to explain simply by an intensification of the domestication process. In addition, can such large-boned animals really be consistent with a domestic type?

A third possible explanation, which on the basis of the data so far illustrated seems to be the most likely, is that the human inhabitants of Rivoli and Arene Candide kept their pigs in free-range conditions, which would encourage interbreeding with wild boars living in the woods around the site. By the Late Neolithic, pigs would be kept under closer control, which would explain size reduction, the genetic isolation of wild and domestic populations, and the increased occurrence of shed teeth found on site (Rowley-Conwy 1997)—the latter an indication that the animals were spending more time in or around the settlement. Isotopic and microwear samples being collected as part of our ongoing study of pig domestication will be closely examined for indications of dietary change between the Early/Mid- and the Late Neolithic pigs that might support this hypothesis.

These examples from the Alpine Neolithic provide some idea of the complexity of detecting early domestic pigs and understanding subsequent developments. As we have seen, simplistic interpretations based on limited data can easily lead to mistakes. In addition, both size and shape have to be considered, as various forms of husbandry can lead to the creation of animals of differing conformation. It has been observed that improved pig breeds found in the archaeological record from the seventeenth century onward have large bones and small teeth (Albarella and Davis 1996; Albarella 2002: Fig.7.2). We now have seen that such relative differences in parts of the body can also be found in prehistoric populations. It is, therefore, worth exploring in more detail whether the early domestication process could bring about, already in its early stages, a reduction in tooth size in comparison to bones.

There are many other possible approaches to shape variation in pigs, and these can all illuminate the domestication process. One method that has not widely been used, but has some history, is the analysis of pig molar morphotypes. Suids have complex molars that can show much intraspecific variation. Cusps can be short or long, and supplementary pillars can be absent or present. These might be considered nonmetric traits, presumably with a genetic origin, and might therefore discriminate between genetically distinct populations (something that could be corroborated by DNA studies). This methodology has been successfully applied by Kratochvîl (1981) to the medieval site of Mikulcice (Czech Republic), and more recently by Warman (2000) on mandibles from various modern breeds and by Fujita (2001) on Japanese wild boars. Current ongoing work by several colleagues and ourselves on Japanese (Jomon/Yayoi) and Polynesian (pre- and postcontact) pigs, has also shown that there is extreme variation in the detailed crown morphology of the permanent dentition, which must reflect genetic variation within and between these populations.

Tooth size in itself represents an insufficient criterion to analyze morphological change, as has also been proven by Mayer et al. (1998). They have demonstrated that, although lower M2 is probably the least useful cheek tooth to discriminate between pig populations on the basis of single measurements, it tends to vary allometrically between domestic and wild animals. In particular, large M2s tend to be relatively longer in wild animals than in domestic ones, while small M2s tend to be relatively shorter in wild than in domestic pigs. If archaeological M2 measurements are sufficiently numerous, it should be possible to construct regression lines for the width/length distribution. It should follow that M2s from wild populations should show a steeper regression line. This is an interesting approach that has so far not been much investigated by zooarchaeologists, but which deserves a greater degree of attention and analysis.

Even when we analyze only tooth metrics, relative differences between different teeth can be noted when comparing populations at different stages in the domestication process, a probable consequence of the gradual shortening of the snout. At the British medieval site of West Cotton, M1s were only marginally smaller than those from the British Neolithic, while the difference was greater in the M2s, and greater still in the M3s (Albarella and Davis 1994; Albarella 2002: Fig.7.6). In other words, teeth placed farther back in the jaw seem to be more affected by the size reduction caused by the intensification of the domestication process.

A similar pattern has been found by Davis (e-mail to Albarella 18 September 2003) in early pig populations from the eastern Mediterranean, suggesting that a progressively greater degree of size reduction as one moves back in the molar row can also separate wild and domestic pigs and therefore detect the origin of domestication. Davis compared the widths of the three lower molars of a relatively large sample of modern wild specimens from Israel and Syria with those from the Aceramic Neolithic of Khirokitia (Cyprus, ca. 6000 BC) and the Ceramic Neolithic of Nahal Zehora (Israel, fifth millennium BC). Both archaeological populations are interpreted as domestic. Molar teeth from modern wild boars are on average wider that those from both sites. However, while the degree of reduction in the width of the first molar

was minimal (6% at Khirokitia and 2% at Nahal Zehora), third molars were subject to a reduction in width greater than 10% at both sites, with M2s providing intermediate values.

Echoing these results, there is also some indication that at the Early Neolithic site of Çayönü Tepesi in southeastern Turkey (10,200–7500 BP uncalibrated), third molars decrease in size (particularly in length) more than do other teeth (Ervynck et al. 2002: 66).This suggests that even in the early stages of domestication, the phenomenon of snout shortening can be detected through differences in tooth-size reduction (see also Flannery 1983). The data from the British medieval site of West Cotton show that the phenomenon intensifies as control increases, and perhaps with the selection of varieties or breeds.

The shortening of the snout (and in fact of the whole skull, with the consequent reduction in brain capacity) almost certainly represents an adaptive phenomenon, connected with changes in diet and lifestyle following domestication. The snout, rather than the tusks, is the most important tool used to dig for food (Nowak 1999: 1054). When such activity becomes less frequent, perhaps as a result of humans supplying food to pigs, this character is no longer selected for, and, in fact, becomes redundant. Since rooting for food can also occur in domestic pigs, these can also have skulls with relatively straight profiles and long snouts. The character is generally used to assess primitiveness in pigs, with highly selected modern breeds having extremely shortened skulls. However, snout shortening could also be linked with a suite of behavioral and physiological changes associated with neotonization, the possible result of human selection for nonaggressive behavior (Trut 1999).

Aging

Modern pigs are generally slaughtered at younger ages than in the past because, as predominantly meat-producers, they will be killed once they have reached full size (except for a few kept for reproduction). Growth is quicker in modern animals than in traditional, unimproved breeds. This is, however, a recent phenomenon, as improved, fast-growing breeds did not become common until late medieval or even early modern times. The speed of growth of a typical medieval pig may not have been much different from that of its Neolithic counterpart, and substantial differences in the age at slaughter of domestic pigs for most of their history are therefore not expected, unless they are based on reasons other than economic.

Variation in kill-off patterns between wild and domestic populations, however, are likely because of the different method of exploitation—in pigs as well as in other species. In particular, a greater number of older individuals would be expected in assemblages deriving from hunting, as the survival of a wild animal beyond its attainment of full size would not have occurred at human expense. Changes in mortality curves are regarded as one of the main criteria in the identification of the beginning of domestication (see Davis 1987).

There are, however, a number of problems with this approach. For example, when wild populations are hunted more intensively, more young animals are killed, creating a quasi-domestic mortality curve (Elder 1965; Rowley-Conwy 2001: 59–60). Such a hunting pattern is especially likely on the threshold of the domestication process when pressure on wild resources was likely quite strong (Davis et al. 1994). Benecke (1993), for example, interprets the young age profiles of pigs from Early Mesolithic to Late Neolithic sites from the Crimean Peninsula as indications of over-hunting and pressure of wild populations and not as a sign of swine domestication.

Seasonality of hunting may also affect the age pattern. Wild boars have quite large litters, and this fecundity means that many very juvenile animals are encountered shortly after the breeding season. In northern Europe, wild boars breed mostly in spring, so assemblages from sites occupied in summer therefore may contain more very juvenile specimens in their first summer. However, such hunting might not be sexually selective but be directed toward both male and female juveniles. Intensified hunting as a prelude to herding, however, might concentrate on juvenile males. A differential sex ratio could provide a possible means for distinguishing seasonality from intensification as the cause of hunting more juveniles, but there are difficulties. Very juvenile animals are the most difficult to sex. In fully domestic populations of sexually dimorphic animals, sex proportions among very juvenile specimens may be extrapolated from the proportions among the adults; for example, if most determinable adults are female, most indeterminable juveniles are probably male. But in hunting, not all members of the population end up on the archaeological site, so it would be difficult or impossible to extrapolate the sexual proportion of the juveniles from that of the adults.

A further problem is that sample sizes must be quite large if changes through time are to be detected, and the chronological sequence must span the period of the suggested onset of food production. This is quite rare for pig assemblages. One site that has produced an important sequence is Çayönü Tepesi in southeastern Turkey. Here there is indeed evidence that pigs were killed at progressively younger ages through the entire Neolithic sequence (10,200–7500 BP uncalibrated), which goes (as previously discussed) hand in hand with a decrease in certain dental measurements (most notably the length of third molar) showing progressive shortening of the snout (Hongo and Meadow 1998; Ervynck et al. 2002).

Although it is likely that these changes represent steps toward greater human control and a closer relationship with the animals, it is difficult to establish when in the Çayönü sequence fully domesticated pigs actually appear. Using multiple lines of evidence, it has been argued that they may appear only in the final phase of occupation (i.e., in the Pottery Neolithic), when there is the first obvious decrease in the width of the teeth and in the size of the postcranial elements. At the same time, there appears to be a marked

increase in physiological stress on the pig population—as reflected in an increase in the frequency of dental enamel defects (Ervynck et al. 2002: 66 and later discussion).

Another site with both a useful chronological sequence and a large bone assemblage is Grotta dell'Uzzo, in northwestern Sicily. At this site, pigs older than four years were observed in Late Mesolithic levels but are no longer found in the Early Neolithic (Tagliacozzo 1993). As at Çayönü, a small size decrease occurs at the same time, although the number of measurable specimens is small and any conclusion must therefore be regarded as tentative. The analysis of a larger sample and of relative size change of different parts of the skeleton—presently in progress by the authors—may provide further information in due course.

Population Genetics

According to most traditional views, the domestic pig originated in the Near East and spread west to Europe and east to China. Some scholars, however, favor the idea that pigs may have been independently domesticated elsewhere (see above for discussion). Limited early studies of the karyotypes of modern wild boar and domestic pig indicate that significant variation exists between pigs in western Europe, Israel, Asia, and the Far East (Popescu et al. 1980; Bosma et al. 1984). These early studies highlighted the potential for cytogenetics to establish whether pig domestication occurred in many areas or just once. Since the 1980s, the rapid development of biomolecular techniques (using both modern and ancient DNA) has resulted in significant advances in our understanding of the molecular evolution of a range of organisms. However, it is only relatively recently that attention has turned toward domestic animals, and even more recently toward pigs.

Recent preliminary research into modern pig genetics has provided rather compelling evidence that appears to support a "multiple domestication" hypothesis. Sequences extracted from hair and blood samples of European and Asian wild boars (7 Japanese, 24 Italian, 15 Polish, and 3 Israeli) and various breeds of domestic pig (n = 74) showed three distinct mtDNA clades—one Asian (A) and two European (EI and EII) (Giuffra et al. 2000; Kijas and Andersson 2001). "A" included Japanese wild boars, Chinese Meishan domestic pigs, and some European domestic pigs. "EI" included the majority of European and all Israeli wild boars, as well as most European domestic pigs and one from the Cook Islands in the Pacific, while "EII" included only 3 Italian wild boars. The considerable genetic diversity noted in this study of modern *Sus scrofa* has been interpreted as providing conclusive evidence for (1) at least two pig domestication events occurring independently somewhere in western and eastern Eurasia, and (2) the later introgression of Asian genetic material into European domestic pigs (Giuffra et al. 2000: 1788).

Although the modern genetic data are extremely important for our broader understanding of pig domestication in Eurasia, they offer few clues with regard to specific geographic context. Nor do they provide any firm temporal framework beyond the crude (and untested) calculations of rates of gene mutation (the so-called molecular clock) that in this case merely indicate a possible divergence of the Asian and European subspecies of wild boar sometime around 900,000 BP (Kijas and Andersson 2001: 307). However, the new and rapidly developing field of ancient DNA (aDNA) research is beginning to provide us with more powerful interpretative tools in these respects.

Some of the only ancient biomolecular research carried out on pigs to date has been undertaken on material from the Japanese archipelago. Using DNA extracted from recent wild boars, as well as from zooarchaeological pig assemblages of primarily Jomon (12,000–2500 BP uncalibrated) and Yayoi (2400–2000 BP uncalibrated) date, researchers have begun to explore the genetic relationships that exist within and between populations of modern/recent and ancient pigs in Japan. Although this research has mainly focused on phylogeographic questions (Watanobe et al. 2001 and 2002; Morii et al. 2002), indirect evidence of pig domestication has also been elucidated. For example, ancient sequence data extracted from pig remains from a number of sites in Southern and central Honshu, suggest that domestic pigs were probably introduced to the Japanese mainland during Yayoi times (Morii et al. 2002: 326). Moreover, those showing sequences most closely related to East Asian domestic pigs were from sites in southern and western Japan (rather than from eastern ones), and all those from the Asahi site in central Japan were more closely related to Japanese wild boar (Morii et al. 2002). Although this current genetic evidence could be used to tentatively suggest that the indigenous Japanese wild boar (*Sus scrofa leucomystax*) appears not to be involved in local domestication events, this limited genetic dataset cannot yet be used to exclude this possibility.

Further research by the same team has also identified an East Asian domestic pig lineage in archaeological material from the Okinawan islands, further supporting their previous conclusion that some pigs were transported from the Asian continent during the early Yayoi-Heinan period (2000–1700 BP), and perhaps even earlier during Jomon times (Watanobe et al. 2002). This evidence appears to cast further doubt on (but again does not rule out) the possible local domestication of the dwarf subspecies of wild boar (*S. scrofa riukiuanus*) indigenous to the Ryuku islands—the remains of which have also been identified through aDNA analysis from archaeological sites in the region (Watanobe et al. 2002).

Ongoing research by our own research team (working with colleagues from England, Sweden, and New Zealand in collaboration with numerous other colleagues and institutions around the world) is currently attempting to understand more fully the phylogenetics of *Sus scrofa* throughout Eurasia. Our aim is to undertake a wide geographical and temporal survey of the extent of possible genetic variation in modern wild boars and archaeological pigs in order to help us understand in more detail specific questions regarding (1) the timing and possible location(s) of domestication (i.e., whether

there were single or separate foci for domestication events, and even where these might have been); (2) the genetic diversity and phylogenetic relationships between wild and domestic pigs in the past; (3) the effects that the processes of isolation, domestication, and feralization had on that genetic diversity; (4) whether species other than *Sus scrofa* have been involved in domestication (as has been claimed for *Sus celebensis* in Indonesia) as well as claims for the existence of hybrids between *S. scrofa* and *S. celebensis* in Papua New Guinea; and (5) the colonization history and possible cultural affinities of animals and peoples in the past through palaeophylogeography.

New data resulting from the analysis of mitochondrial DNA extracted from the teeth of 223 recent wild boars/feral pigs across Eurasia, compared with an additional 471 previously published wild, domestic, and feral *Sus* sequences available on Genbank, have provided some exciting and somewhat controversial initial results (Larson et al. 2005) which can be briefly summarized as follows:

1. Perhaps the most fundamental insight is the fact that some *Sus* species designations (i.e., *Sus celebensis, S. verrucosus, S. barbatus*) based upon morphological criteria are not supported by our mitochondrial DNA data. Each of these groups clusters not with each other, but within the variation of *Sus scrofa* as a whole.
2. *Sus scrofa* as a species originated somewhere in Island Southeast Asia (Philippines, Indonesia).
3. There are a number of extant wild *Sus scrofa* lineages from which recent domestic animals do derive, clearly indicating that pig domestication occurred independently in several diverse geographic locations across Eurasia. Thus, in the Far East, there appears to be a likely minimum of three (but possibly more) wild lineages that were domesticated (two in China and additional ones in Burma/Thailand and northern India). From Wallacea (samples from Halmahera and Papua New Guinea), there is possible evidence for the independent domestication of an introduced ancient lineage of pigs from elsewhere in Island or South East Asia not so far sampled by us. But perhaps most exciting is clear evidence from Europe that points to the independent domestication of probably two wild lineages that form the basis for all modern European breeds (including those that were later improved by mixing with Asian types).
4. Intriguingly, all modern European breeds in our sample have either a European or an Asian "signature." None is even remotely similar to sampled recent wild boar lineages from Armenia, Iran, or Turkey, suggesting little or no importation of Near Eastern domestic pigs into Europe by early farmers.

The conclusions are all based on data deriving from recent or modern, wild or domestic boars and pigs. However, over 500 archaeological samples have also been collected and recently processed and sequenced from over 50% of these samples. These preliminary (and as yet unpublished) data largely support our original published conclusion based on moedern mtDNA, although they add further complexity to the existing picture.

Ancient Diet and Health

The changes in behavioral ecology that occur with domestication provide a promising, yet often neglected, area of research. In particular, changes both in the diet and in the health of animals are potentially very important research tools for identifying the processes of domestication. Adequate fodder must have been one of the defining variables for the success or failure of domestication experiments. Human control over the diet of domestic stock must inevitably have led to a dichotomy between the diets of wild and domestic populations, and this would perhaps have been most exaggerated in omnivores such as pigs. Pigs' omnivory might have led to a more straightforward transition to human control than would have occurred for herbivores such as sheep and goats. Hongo and Meadow (1998: 77) have suggested that the processes of pig domestication were more similar to those of the dog than to those of other artiodactyls. One major reason cited was the fact that both pigs and dogs are more generalized omnivores, more likely to have been drawn to human settlements to feed on refuse. In fact, Ervynck et al. (2002: 68) have suggested that possible early morphological and biometrical changes to the skulls of pigs at Çayönü were related to changes in the rooting behavior of wild individuals, perhaps attracted to human settlements by new food sources such as crops or human refuse.

Regarding health, if natural selection favors hardier individuals, one would expect that the frequency of conditions detrimental to health would normally be low in a "natural" or truly "wild" population (Ervynck et al. 2002: 69). At the other extreme (e.g., in a tightly managed population), higher densities of animals, changes in demographic structure, or poor husbandry strategies ought to lead to the disturbance of the animal's natural behavior and feeding regimes (Price 1984: 14). As a result, it could theoretically be expected that a significant rise in pathological conditions should also be a consequence of early domestication attempts. This has been perhaps most aptly demonstrated in horses, where specific skeletal (joint arthropathies) and dental ("bit wear") abnormalities, thought to be linked primarily to riding, have been used as criteria to signal early domestication (e.g., Anthony 1996; Levine et al. 2000; but see Chapter 17). Work on the health status of ancient pigs, however, has been much more limited.

These broad themes can be explored using a variety of approaches and techniques, and the following are examples of those we and others have recently applied to archaeological pigs.

FIGURE 15.6 *Sus* mandible from second millennium BC deposits at Chagar Bazar, northern Syria, showing abnormal wear and breakage of the tooth crowns (photos by Augusta McMahon).

FIGURE 15.7 *Sus* mandible from second millennium BC deposits at Chagar Bazar, northern Syria, showing heavy dental calculus deposits (photos by Augusta McMahon).

EVIDENCE FROM TOOTH WEAR AND DENTAL CALCULUS

The mouth is the place where the initial physical and chemical breakdown of food occurs. Teeth are the means of shearing, chopping, and masticating and, as such, will be affected to varying degrees by any major changes in the physical and chemical makeup of ingested food. Normal progressive wear on the teeth at a macroscopic level has provided a methodology by which to estimate the relative age at death of ancient pigs (Grant 1982). However, macroscopic and microscopic studies of tooth wear may also provide clues as to changes in the physical properties of the diet.

The study of microscopic tooth wear (dental microwear) has a relatively recent and varied pedigree in the dietary reconstruction of a wide range of extant and fossil species (e.g., Teaford and Runestad 1992; van Valkenburgh et al. 1990; Strait 1993; Solounias and Hayek 1993). Ward and Mainland (1999) showed that modern free-range/rooting pigs had a greater density of microwear features on the buccal and occlusal surfaces of their teeth compared to modern stall-fed pigs. This difference in wear patterns was attributed to the more abrasive diet of free-range/rooting pigs that ingested more soil during feeding. Although microwear studies on modern and archaeological pigs are few and far between, this study, and research on other domestic species such as sheep (e.g., Mainland 1998), has shown the potential of the method for highlighting major differences in diet between archaeological populations.

Major changes in dietary components can also result in chemical changes in the oral environment, which can also indirectly manifest themselves on the dental tissues by stimulating or suppressing different kinds of oral bacteria. A lowering of the pH of saliva, for example, will lead to an increase in cariogenic oral flora (those that cause caries lesions), while an increase in pH is more likely to lead to the calcification of elements of the oral flora, so forming dental calculus. Thus, changes in the frequency of caries or calculus within populations can potentially indicate shifts in diet most likely linked to human husbandry practices.

While major changes in diet would not be expected in the early phase of domestication, such occurrences cannot be ruled out, particularly if poor or initially inappropriate husbandry practices were employed. Also, when fully domesticated pigs were introduced to an area where indigenous wild boars were also present, major differences in the diet and health of these populations (manifested by the conditions outlined above) could be used to separate them in the zooarchaeological record. During our extensive study, the most marked examples of severe calculus formation, caries development, and abnormal wear have been recognized only from sites where fully domestic pigs were certainly present.

For example, pigs are an important component of vertebrate assemblages recovered from fifth to second millennium BC sites (e.g., Tel Brak, Leilan, Chagar Bazar) from the steppe region of the Khabur, northern Mesopotamia, ranging in frequency from between 20 and 60% of the domestic animal remains identified. Changes in the exploitation of pigs and caprines have been explained in a number of ways that primarily focus on environmental, socioeconomic, and political factors (e.g., Zeder 1998a and b; 2003a; Dobney et al. 2003). Recent dental analysis has shown that the pigs from the site of Chagar Bazar have a high frequency of abnormal wear (29% of pig mandibles from second-millennium deposits) and dental calculus (11%) (Figures 15.6 and 15.7). In numerous cases, large portions of the cheek teeth have been broken antemortem and then subsequently worn further by mastication. In many of the same mandibles, "severe" deposits of dental calculus have also been noted, usually on the buccal surfaces of the premolars. These pathologies can probably be explained by an unusual behavior or diet of the pigs at these sites.

In semi-arid regions such as northern Syria, where shade is limited, pig keeping would have been severely constrained by both ecological and maintenance factors. Their high water requirements, and an inability to utilize cellulose-rich pasture plants, means that pigs are best kept close to or within the settlement. So, in densely settled areas (like these early city-states), small-scale, enclosed pig keeping was likely the norm. As such, pigs would have been unable to carry out extensive rooting and would have been fed a range of domestic human refuse. The presence of these oral pathologies, in higher frequencies than normally found, must reflect a shift in diet and behavior related to human husbandry practices and may indicate examples of urban pig keeping.

DEVELOPMENTAL STRESS: LINEAR ENAMEL HYPOPLASIA

Mammal teeth can provide many clues to an individual's living conditions. Linear enamel hypoplasia (LEH) is a deficiency in enamel thickness occurring during tooth crown formation, typically visible on a tooth's surface as one or more grooves or lines (see Goodman and Rose 1990 for a detailed discussion of the hypoplastic lines in humans). The condition is generally caused by developmental stress (Sarnat and Moss 1985). The causes may vary, but nutritional deficiencies are certainly important factors. For humans, the analysis of LEH has been used successfully to assess the general health status of archaeological and recent populations (e.g., Goodman et al. 1988).

Recent studies on pigs have developed a recording protocol for this condition (Dobney and Ervynck 1998), recorded its frequency and chronology in numerous archaeological pig assemblages of varying date and location (Ervynck and Dobney 1999; Dobney and Ervynck 2000; Dobney et al. 2002), and even explored its use in identifying second farrowing (Ervynck and Dobney 2002). These analyses have shown that LEH is common in pigs, but is certainly not a random event. Its occurrence follows clear patterns that reflect causal relationships between events in life and seasonal conditions affecting the individual's food intake and energy balance.

Recent work on Neolithic (Pre-Pottery and Pottery) pigs from the site of çayönü Tepesi has shown very low frequencies of LEH as compared to much later northern European Neolithic and medieval site assemblages (Ervynck et al. 2002: Figure 23)—something that should perhaps be expected from a healthy, wild population in a relatively undisturbed natural environment. However, there did appear to be a slight increase the frequency of LEH through the three Pre-Pottery Neolithic phases (indicated by slight changes in LEH frequency; see Ervynck et al. 2002: Figure 22), as well as a more obviously significant increase between the Pre-Pottery and Pottery Neolithic phases (Ervynck et al. 2002: Figure 23).

Could these changes in LEH frequency also reflect human intervention and early domestication attempts at Çayönü? It has been argued that the change during the Pre-Pottery phases may simply reflect individual differences in behavior within the wild population (Ervynck et al. 2002). Changes in feeding behavior could have led to increased physiological stress in those particular animals but do not necessarily reflect direct human influence over them, at least in the earliest Pre-Pottery phases. It is as yet unclear from the Çayönü sequence when humans began to play a more active role in pig management. However, it could be argued that the significant increase in LEH frequencies noted in the Pottery Neolithic may well mark this transition.

A more recent large-scale study of both recent and archaeological *Sus scrofa* remains from northwest Europe showed the frequency of LEH to be consistently low within all ancient and recent wild boar populations studied, in contrast to early domestic populations of Neolithic date, which show generally higher LEH frequencies (Dobney et al. 2004). As was the case at Çayönü, higher frequencies of LEH in these ancient pig populations have also been broadly interpreted as being the result of direct or indirect human interference related to domestication and husbandry.

ISOTOPES

Of all the approaches to the study of ancient diet, perhaps the greatest potential lies in the field of stable isotope analysis, where the most rapid developments are also taking place. This approach can tell us about the changing diets and adaptations of mammals, and more about the environment in which they lived. Techniques of analysis now allow the fairly routine collection of measurements of both $\delta^{13}C$ and $\delta^{15}N$ in a wide range of animal material, which in turn have provided a range of important dietary information for a range of species including humans (e.g., Fizet et al. 1995; Richards et al. 2001; Bocherens et al. 2001), and in some cases have distinguished wild from domestic animals (e.g., Balasse et al. 2000).

The relative importance of terrestrial vs. marine products ingested can also provide information about the trophic level of the animal in the food chain. Thus, within a single ecosystem, the diets of herbivores, carnivores, and omnivores can theoretically be identified. Pigs (like dogs and humans) are essentially omnivores, so they can show a range of $\delta^{13}C$ and $\delta^{15}N$ values, which range from those most commonly found in herbivores to those of carnivores. Wild boars are probably largely herbivorous, but domestic pigs are more likely to have become increasingly carnivorous through consuming human waste and excrement. Thus, there should be interpretable patterns through time that are related to human influence on the diet of pigs (Richards et al. 2002).

Research into the diet of pigs using stable isotopes is as yet relatively limited. However, preliminary and ongoing work by several colleagues has begun to test a number of general hypotheses concerning isotopic signatures for pig domestication and husbandry. For example, isotopic analysis has been undertaken on Jomon-age pig bones from the Ryuku and other islands in the Japanese archipelago in order to test the hypothesis that wild boar diet changed during the initial stages of domestication (Minagawa and Matsui 2002). Comparison of $\delta^{13}C$ and $\delta^{15}N$ values led the authors to conclude that two feeding strategies were developed for domestic pigs: one based mainly on human leftovers and the other on feeding pigs cultivated C_4 plants or marine foods (Minagawa and Matsui 2002: 106).

Preliminary results of $\delta^{13}C$ and $\delta^{15}N$ values from nine European sites are also available (Pearson 2001; Richards et al. 2002). At most of these sites, pigs indeed appear to be mainly herbivorous (i.e., more negative $\delta^{13}C$ and associated low $\delta^{15}N$ values). This suggests that if humans controlled pig diets, this control involved feeding pigs (or allowing pigs to feed on) mainly plant foods. This herbivorous diet is typically

found in European wild boars (Briedermann 1990) and would presumably have been very similar for domestic pigs herded in woodland areas. Preliminary results suggest that only at later sites (i.e., Iron Age and medieval) are there pigs that show $\delta^{13}C$ and $\delta^{15}N$ values consistent with the consumption of more animal products and/or human waste.

The results from the Middle and Late Neolithic site of Arbon (Switzerland) (Richards et al. 2002) are also important. The $\delta^{13}C$ and $\delta^{15}N$ values from large specimens (presumed to be wild) and smaller specimens (presumed to be domestic) show very little difference, implying a very similar—mostly herbivorous—diet. These data would suggest that the diets of wild and domestic pigs exploited at the site were similar.

Isotopic analysis as a tool to assess the diet of ancient domestic animals is increasing in its importance to zooarchaeologists. The field is, however, a young and rapidly developing one, and there is still much we do not understand about the processes involved. More samples must be analyzed before results such as those outlined above can be more meaningfully interpreted. The results also cannot be interpreted in isolation: values from other species, and other related zooarchaeological information, needs to be considered. We need to establish just what we mean by a typical nondomesticated pig diet as reflected in stable isotopes, by looking at modern wild boars and (probably more usefully) clearly predomesticated individuals (i.e., Late Pleistocene and Early Holocene specimens). Ultimately, we need to carry out controlled feeding experiments to construct more reliable interpretative frameworks. It may be, however, that any shifts that took place in the diet of early domesticated pigs were too subtle to detect with the crude ("averaging") tool of stable isotopes in bone collagen. However, the microsampling of dental tissues offers the promise of exploring more subtle changes within the lifetime of a single individual. Alternatively, major changes in diet are perhaps not linked with domestication at all, but perhaps occurred much later during urbanization and the related intensification of husbandry techniques, aspreviously suggested for second millennium sites in northern Syria.

Establishing Temporal Context for Initial Pig Domestication

Establishing the temporal context of pig domestication is not as easy as it is for some other species for two reasons. First, as we have discussed, there are many potential types of pig-human relationships. Correctly identifying the relationship(s) at any archaeological site is only the first step; we must then decide which ones we admit within our definition of domestication. Secondly, we have also seen that the widespread distribution of wild boars has allowed a variety of origins to be suggested.

The site of Çayönü Tepesi has been mentioned several times in the course of this chapter, and it is perhaps one of the most important and earliest sites in Eurasia in which pig domestication has been studied. As previously discussed, its unique, long chronological sequence (covering the entire Pre-Pottery and Pottery Neolithic periods) provides one of the very few opportunities to create a temporal framework within which to document the process of domestication in some detail. Thus, visible changes to the skeleton and teeth (e.g., snout shortening and change in conformation), evidence for an increase in physiological stress, and a shift in demographic profile indicate a process that appears to have been very slow—occurring gradually over approximately 2,000 years and apparently complete by the start of the Pottery Neolithic (around 8000–7500 BP uncalibrated). Perhaps what is most interesting about the evidence from Çayönü is the fact that these changes were not all coeval, suggesting a more complex physiological and behavioral response, perhaps not originally driven by direct human intervention (Ervynck et al. 2002).

Finds from Hallan çemi Tepesi, a Turkish site in the eastern Taurus Mountains, has suggested an even earlier date for the first shift within a *Sus scrofa* population from completely "wild" behavior to a way of living closer to humans (Rosenberg et al. 1995, 1998). However, while the measurements of the five recovered lower third molars from Hallan çemi Tepesi are surprisingly small, the dataset is limited. In a review of *Sus* data from sites more recent than Çayönü or contemporary with its later Pre-Pottery phases, Peters et al. (1999) observed a decrease in the length of the third molar between PPNB material from Çayönü and LPPNB specimens from Gürcütepe (Peters et al. 1999: Figure 11). The authors claim this to be "unequivocal morphometrical evidence for the occurrence of domestic pigs" in the LPPNB as a somewhat rapid, punctuated event. However, the Çayönü data presented in Peters et al. (1999) represents an amalgam of teeth from the Channeled to the Cell Plan Building phases, which covers the whole PPNB. When data from the different subphases of the PPNB at Cayönü are examined separately, one can see clear evidence for decrease in the size of third molar occurring over the course of this long period (Ervynck et al. 2002).

Peters et al. (1999) also highlight data from other LPPNB sites such as Hayaz Tepe and Tell Hallula to substantiate their claim for the appearance of domestic pigs in that chronological period. However, why the *Sus scrofa* specimens from Hayaz Tepe and Tell Hallula should be labeled "domestic" is not clear from the review. In fact, a comparison of the postcranial data from Gürcütepe and older sites (not Çayönü) rather indicates a continuous (slight) size decrease through time instead of a sudden change between the Middle and Late PPNB (see Peters et al. 1999: Figure 10).

In addition to southwest Asia, there is tentative evidence for another domestication event occurring in China, and the site of Cishan points to a similar time period as that from southeastern Turkey (i.e., around 8000 BP). Although limited data exist to support this claim (Jing and Flad 2002;

Giuffra et al. 2000; Kijas and Andersson 2001), a more detailed analysis similar to that outlined above needs to be undertaken in order to confirm this and to see to what degree the specific processes involved are similar or different.

Once these issues are resolved, it is vital that selected specimens are directly dated by accelerator mass spectrometry (AMS) radiocarbon dating techniques. These should preferably be specimens actually showing some significant feature or trait, not just some bone from the same layer or context. This is because individual objects can move between archaeological contexts, before or during excavation. Naturally, we are eager to find early examples of important developments like domestication and are, therefore, sometimes uncritical in our acceptance of contextual data from complex sites (see Rowley-Conwy 1995).

Future Research

Our aim in this chapter has been to stress the multiple methods that should be applied to the questions of pig domestication. Future research will use these methods to test some of the ideas put forward above. Were there really only two separate hearths of domestication, in the Near and the Far East respectively? Our recent genetic research suggests not. The intervening areas are much less well known, and substantial swathes of the map remain a blank—our equivalent of the medieval cartographers' "here be dragons." Establishing what was going on in between the Near and Far East hearths is now a priority and will be a significant test of the validity of the "twin hearth" model.

What of other potential areas of domestication indicated by recent genetic research? The Baltic region may have seen the intensification of wild boar exploitation, and even local domestication (Zvelebil 1995), and a major goal is to establish whether or not this was actually the case. The Indian subcontinent is another area, currently unknown, from which interesting results may be confidently predicted. Finally, the status of the various modern *Sus* lineages in peninsular and island Southeast Asia needs to be sorted out as a matter of priority. This should go hand in hand with the study of archaeological materials in this region. The results will be of great importance to our understanding of human dispersal and the settlement of the Pacific, when pigs accompanied humans on the greatest diaspora ever undertaken by either species.

Notes

1. *Sus celebensis* (the Sulawesi warty pig) has been claimed to have been involved in a separate domestication event in Indonesia during the early Holocene (Groves 1981).
2. This is based on subtle variations in cranial morphology of a small sample of modern specimens he measured.
3. There are those that claim it to be by about 6000 BP or even earlier (Golson and Hughes 1976; Golson 1982), while others favor a more recent introduction (Bayliss-Smith 1996; Harris 1995) based on radicarbon dates (Hedges et al. 1995). Bulmer (conversation with Dobney, 12 September 2002) argues that these dates are likely to be in error in light of the firm stratigraphic position of pig bones in Late Pleistocene or Early Holocene contexts in at least four sites.

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